

with measurements over a variety of radial paths containing forest, building, and snow cover (NTIA Technical Memorandum 82-80 by Kissick and Adams, limited distribution); (2) a complete study of the limits of WAGSLAB for long paths and high frequencies; (3) consideration of a switch from the integral equation approach to multiple knife-edge diffraction for long, rough paths; and (4) the addition of an additional height-gain function for the magnetic field which would be applicable to reception with loop antennas. The height-gain functions for the vertical electric field and the horizontal magnetic field are equal in free space, but are different within the slab medium. This difference has been observed experimentally in cities and forests at MF by Causebrook (1978b). In addition it might be possible after a comparison with measurements to improve the theory for the equivalent slab parameters for cities or to infer the equivalent parameters directly from measurements.

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9. REFERENCES

- Abramowitz, M., and I. A. Stegun (1964), Handbook of Mathematical Functions, National Bureau of Standards, AMS 55.
- Bremmer, H. (1949), Terrestrial Radio Waves (Elsevier Publishing Company, Amsterdam).
- Causebrook, J. H. (1978a), Medium-wave propagation in built-up areas, Proc. IEE 125, pp. 804-808.
- Causebrook, J. H. (1978b), Electric/magnetic field ratios of ground waves in a realistic terrain, Electronics Letters 14, pp. 614-615.
- Cavalcante, G. P. D. S., D. A. Rogers, and A. J. Giarola (1982), Analysis of electromagnetic wave propagation in multilayered media using dyadic Green's functions, Radio Sci. 17, pp. 503-508.
- Defense Intelligence Agency (1971), Basic phenomena involved in MF and HF radio communications, ST-CS-06-13-71, Appendix III.
- Dence, D., and T. Tamir (1969), Radio loss of lateral waves in forest environments, Radio Sci. 4, pp. 307-318.

- Evans, S. (1965), Electrical properties of ice and snow--a review, *J. Glaciology* 42, pp. 773-792.
- Gordon, G. A., and E. Hoyt (1982), An estimate of HF/VHF surface-wave communication link reaches in the West German forest environment, RDA-TR-119930-001, R & D Associates, Marina del Rey, California.
- Hill, D. A., and J. R. Wait (1980), Ground wave attenuation function for a spherical earth with arbitrary surface impedance, *Radio Sci.* 15, pp. 637-643.
- Hill, D. A., and J. R. Wait (1981a), HF ground wave propagation over mixed land, sea, and sea-ice paths, *IEEE Trans. Geosci. Remote Sensing* GE-19, pp. 210-216.
- Hill, D. A., and J. R. Wait (1981b), HF radio wave transmission over sea ice and remote sensing possibilities, *IEEE Trans. Geosci. Remote Sensing* GE-19, pp. 204-209.
- Hill, D. A., and J. R. Wait (1982), Ground wave propagation over a mixed path with an elevation change, *IEEE Trans. Ant. Prop.* AP-30, pp. 139-141.
- Hufford, G. A. (1952), An integral equation approach to the problem of wave propagation over an irregular terrain, *Quart. J. Appl. Math.* 9, pp. 391-404.
- Hufford, G. A., A. G. Longley, and W. A. Kissick (1982), A guide to the use of the ITS irregular terrain model in the area prediction mode, NTIA Report 82-100.
- Jansky and Bailey Research and Engineering Department (1966), Tropical propagation research, final report, Vol. 1, Atlantic Research Corp., Alexandria, Virginia.
- Millington, G. (1949), Ground wave propagation over an inhomogeneous smooth earth, Pt. 1, *Proc. IEE* 96, pp. 53-64.
- Monteath, G. D. (1973), Applications of the Electromagnetic Reciprocity Principle (Pergamon Press, Oxford).
- Ott, R. H. (1971a), An alternative integral equation for propagation over irregular terrain, *2, Radio Sci.* 6, pp. 429-435.
- Ott, R. H. (1971b), A new method for predicting HF ground wave attenuation over inhomogeneous, irregular terrain, U.S. Dept. of Commerce, Res. Rept. No. OT/TRER 7, January (NTIS Accession No. AB721179).
- Ott, R. H., and L. A. Berry, (1970), An alternative integral equation for propagation over irregular terrain, *Radio Sci.* 5, pp. 767-771.
- Ott, R. H., L. E. Vogler, and G. A. Hufford (1979), Ground wave propagation over irregular, inhomogeneous terrain: comparison of calculations and measurements, NTIA Report 79-20 (NTIS Accession No. PB 298668/AS).
- Ott, R. H., and J. R. Wait (1973), Excitation mechanisms for transmission through forest-covered and vegetated media, U.S. Department of Commerce, Office of Telecommunications, Boulder, Colorado, Technical Report No. ACC-ACO-8-73 prepared for U.S. Army Communications Command, Ft. Huachuca, Arizona (NTIS Accession No. AD 771-915).

- Parker, H. W., and G. H. Hagn (1966), Feasibility study of the use of open-wire transmission lines capacitors and cavities to measure the electrical properties of vegetation, Stanford Res. Inst., Special Tech. Rept. 29, Menlo Park, CA.
- Parker, H. W., and W. Makarabhiromya (1967), Electric constants measured in vegetation and in earth at five sites in Thailand, Stanford Res. Inst., Special Technical Report 43, Menlo Park, California.
- Tamir, T. (1967), On radio-wave propagation in forest environments, IEEE Trans. Ant. Prop. AP-15, pp. 806-817.
- Tamir, T. (1977), Radio wave propagation along mixed paths in forest environments, IEEE Trans. Ant. Prop. AP-25, pp. 471-477.
- Van der Vis (1979), Measurements on short distance HF data links, National Defense Research Organization TNO, Report IR 1979-72.
- Vogler, L. E. (1981), The attenuation of electromagnetic waves by multiple knife-edge diffraction, NTIA Report 81-86 (NTIS Accession No. PB 82-139239).
- Von Hippel, A. (1954), Dielectric Materials and Applications (Technology Press of MIT, Cambridge).
- Wagner, C. (1953), On the numerical solution of volterra integral equations, J. Math. Phys. 32, pp. 289-401.
- Wait, J. R. (1959), Guiding of electromagnetic waves by uniformly rough surfaces, Pts. 1 and 2, IEEE Trans. Ant. Prop. AP-7, pp. 5154-5168.
- Wait, J. R. (1962), Electromagnetic Waves in Stratified Media (Pergamon Press, New York).
- Wait, J. R. (1967a), Radiation from dipoles in an idealized jungle environment, Radio Sci. 2, pp. 747-750.
- Wait, J. R. (1967b), Asymptotic theory for dipole radiation in the presence of a lossy slab lying on a conducting half-space, IEEE Trans. Ant. Prop. AP-15, pp. 645-648.
- Wait, J. R., R. H. Ott, and T. Telfer (1974), Workshop on radio systems in forested and or vegetated environments, Technical Report No. ACC-ACO-1-74, U.S. Army Communications Command, Fort Huachuca, Arizona.
- Wait, J. R., and L. C. Walters (1963), Curves for ground wave propagation over mixed land and sea paths, IEEE Trans. Ant. Prop. AP-11, pp. 38-45.

